特別掲載

The absorbed dose in a whole body from 44keV, 105keV X-rays and ^{60}Co γ-rays

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X線およびγ線による全身被ばくの際の吸収線量

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水ファントム中の照射線量分布を電離箱を用いて計り，その結果を用いて全身被ばくの際の頭部，胴部，上肢，下肢および全身の吸収線量を求めた．測定は 44 keV, 105 keV Ｘ線および ^{60}Co γ線を用いておこなつた．放射線の入射方向は人体に対し前方45° 角度および側方入射であつた．

水ファントムは５㎜のポリエチレン製で，切口が20×30㎝，12×17㎝のだ円，および10㎝直径の円で高さは60㎝である．電離箱の中心は水面より15㎝で，照射野は30×30㎝である．照射線量分布はファントムがない場合の空中線量１Ｒに対するもので，測定結果に距離の減弱を補正した．吸収線量は，照射線量分布の等線量曲線の間の面積を面積計で測定し，その面積，その領域の中間の照射線量および R-rad 変換係数の積をその部位の全面積でわるとえられる．全身吸収線量は前方入射に対してやや大きく，全体として空中線量１Ｒに対し 0.4～ 1.0rad であつた．

Abstract

The absorbed dose in the parts of head, arms, abdomen, legs and whole body has been obtained for a homogeneous phantom from the radiations, 44 keV, 105 keV X-rays and ^{60}Co γ-rays by measuring the exposure distributions in water phantoms with an ionization chamber. The direction of a phantom was in front, side and at an angle of 45 degrees to the beam. The amount of absorbed dose in the whole body obtained was 0.4 to 1.0 rad for 1R of free air exposure.

Introduction

In the measurement of personal monitoring, the assessment of absorbed dose in terms of personal monitor reading is most important, but the rule of it is not fully established yet. As the monitor is usually loaded on the chest or abdomen of a human body, the measured value of a monitor indicates only the accumulated dose at the location of the monitor.

The ICRP has recommended that the absorbed dose which should be assessed is that in the gonads or in the bone marrow in case of a whole body exposure.[1] J.R. Jones has determined the relations between the monitor reading or the exposure to the monitor site and the absorbed dose in the critical organs such as brain, eyes, skin, gut mucosa, ovaries, testis and average bone marrow.[2][3] He has measured the absorbed dose in the Alderson phantom with a LiF thermoluminescent dosimeter in the energy range of 27 keV to 1.25 MeV. The results have been used by E. Piesch in the interpretation of absorbed dose in the critical organs by the radiophotoluminescent dosimeter encapsuled in the holed cadmium case.[4][5] H.J. Delafield has measured the exposure distribution in water phantoms, and determined the method of calculation of absorbed dose by the film badge readily.[6]

The absorbed dose in critical organs, of course, is to be known in radiation hazard, but that in the whole body is also important in case of a whole body exposure. The ICRP stated about this in the item 25 in ref. (1). Further, the knowledge of the amount of the absorbed dose in the whole body is essential in radiation accident. W.A. Langmead and S.M.B. Hill have determined the dose of person who experienced an accident in the handling of nuclear power fuels.[7]

In the present work, to determine the dependence of the absorbed dose in the whole body on the direction of man to the radiations and on the energy, the exposure distributions in water phantoms were measured with an ionization chamber for three kinds of energies and three kinds of directions. The comparison of the data with those obtained by other author will be made.

Experiments

(1) Radiation source

Radiation sources used in the experiments were 44 keV, 105 keV X-rays and ^{60}Co γ-rays. The X-rays were generated at the potential of 95 kV and 230 kV; added filters were 5 mm Al and 1.5 mm Cu + 0.5 mmAl, respectively. The effective energies were determined by measuring a half value layer thickness with aluminum and copper wedges. All the following experiments were made at a distance of 3.4 m from the sources. The dose rate was about 0.3, 1.0 and 0.03 R/min for 44 keV, 105 keV X-rays and ^{60}Co γ-rays, respectively.

(2) Exposure distributions in water phantoms.

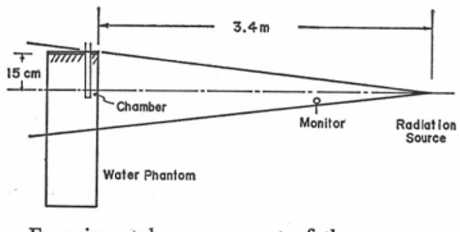

Fig. 1. Experimental arrangement of the measurement of exposure distributions in water phantoms.

Experimental arrangement to measure the exposure distributions in phantoms is shown in Fig. 1. The phantoms were made of 5 mm thick polyetylene sheet, filled with water. The cross-sections are shown in Fig. 2, and the height was 60 cm. The center of the chamber was placed at a depth of 15 cm from the water surface. The field size was 30 × 30 cm. Phamtom directions were in front, side and at an angle of 45 degrees to the incident beams. A Farmer-Baldwin ionization chamber for sub-standard use was

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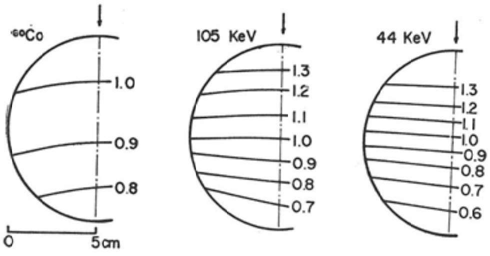
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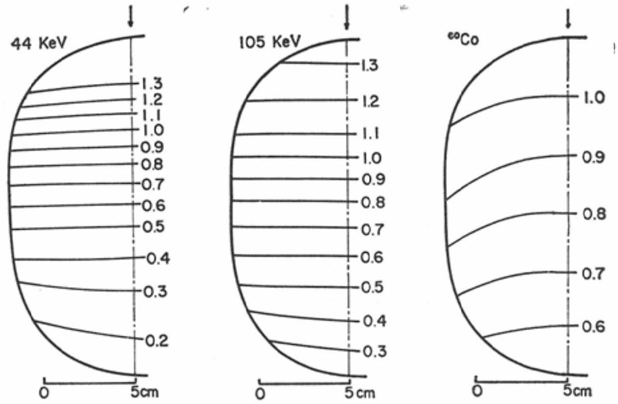
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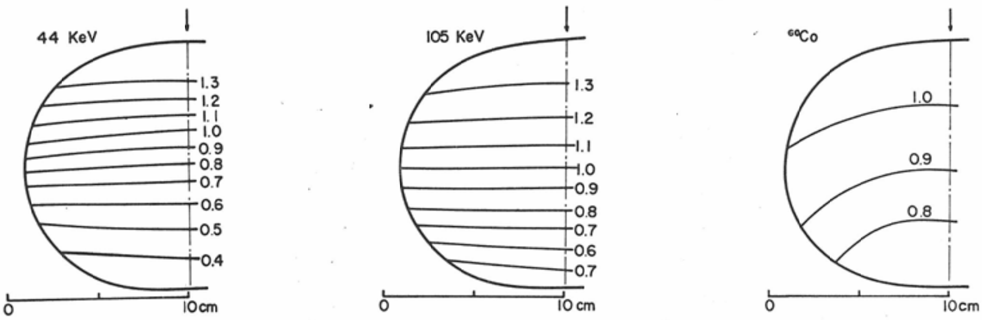
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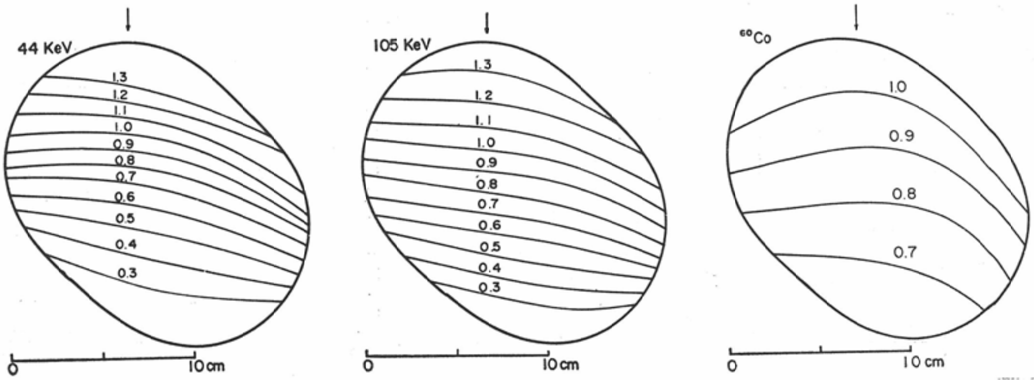
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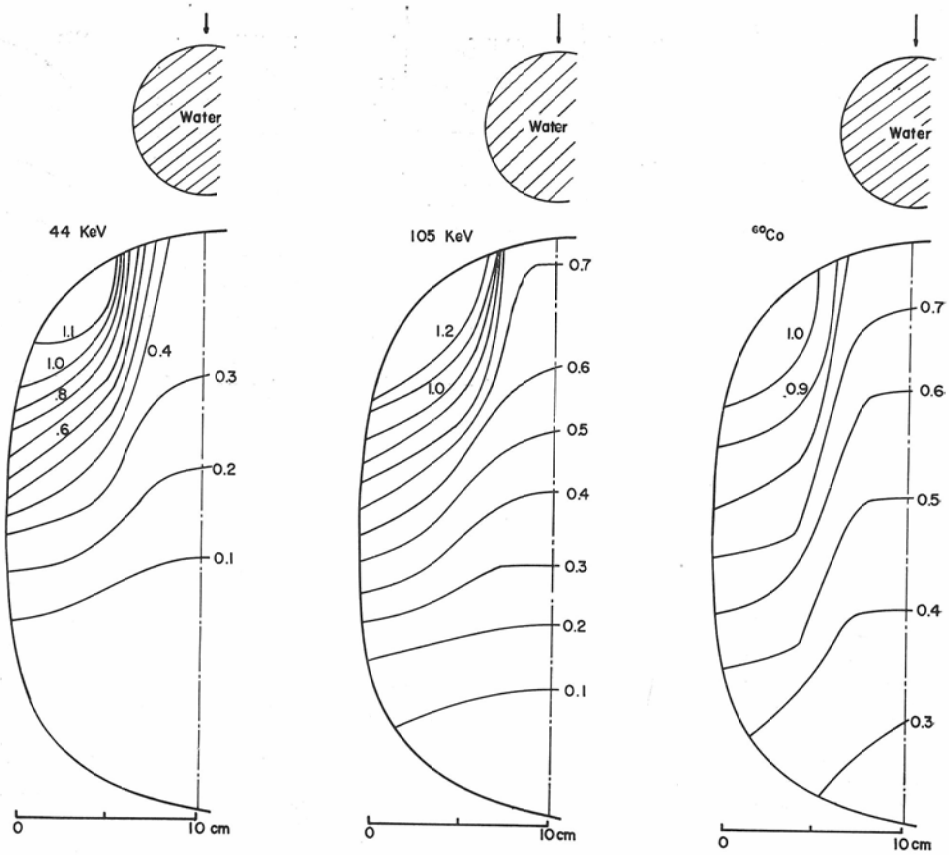
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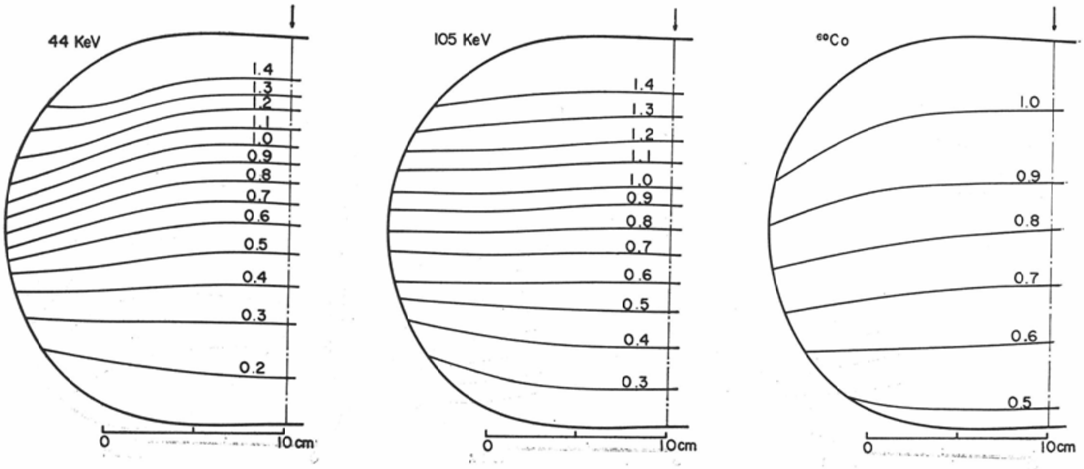
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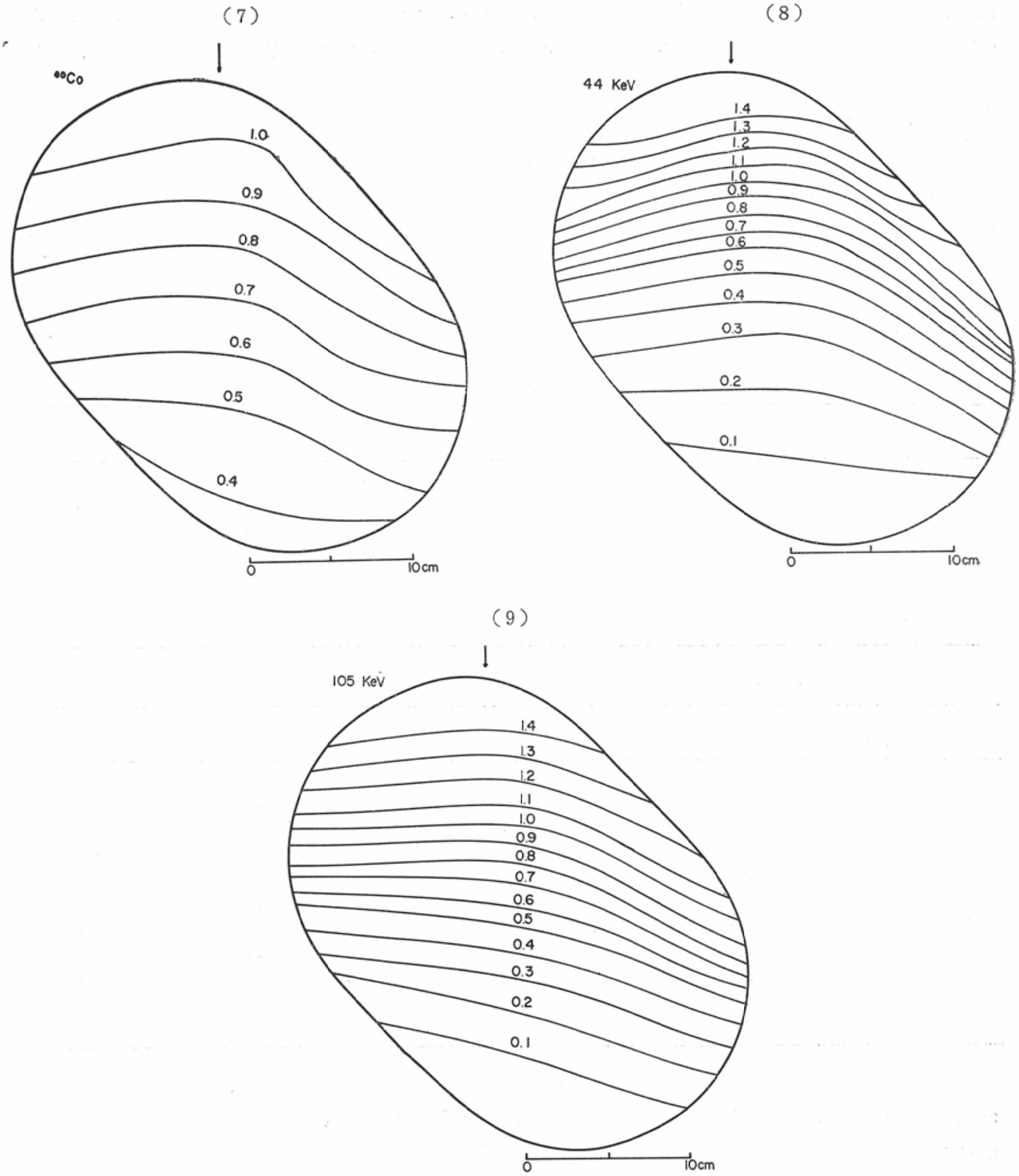


Fig. 2. Exposure distributions for man phantom normalized to the free air exposure 1R and applied the inverse square law correction. Arrow shows the direction of radiation incidence.

used. The energy dependence of it has been measured at the National Physical Laboratory in England. The correction factors are 1.10, 0.99, 1.015 and 1.05 for photon energies of 25, 80, 120 keV and 1.25 MeV relatively. The measured points in the phantoms were of 2 or 3 cm apart mesh, and to a distance of 1.5 cm from the surface of the phantom. Distributions in Fig. 2 were obtained by normalizing the exposure in the phantom to the free air exposure at the point of the phantom surface and applying the inverse square law corrections.

Absorbed dose calculation

The cross-sections of a man phantom used in the calculation of absorbed dose were essentially the same as these used in the measurements of exposure distributions. The sizes are shown in Table 1, in which these of legs, thighs and arms were slightly different. The distributions for these parts were obtained from the data of the similar size phantom by the method in which a sheet of transparent paper was laid over the measured distributions and the line of periphery of the arms, etc. and the combined lines were traced.

Table 1. Dimensions of Parts of Man Phantom

Part of Phantom	Shape	Major (cm)	Minor (cm)	Length (cm)	Area (cm^{-2})	Volume (cm^{-3})
Head	elliptical	18	13	20	199	3980
Chest & Abdomen	〃	31	21	60	563	33780
Thighs	circular	14		30	154	2 × 4620
Legs	〃	11		40	95	2 × 3800
Arms	〃	9		30	64	2 × 1920
Under arms	〃	7		30	39	2 × 1170
Total						60750

Table 2. Average absorbed dose of man-phantom exposed to radiation of 1R. (rad)

Part of Phantom	Front & Back ^{60}Co	Front & Back 105keV	Front & Back 44keV	45 degree ^{60}Co	45 degree 105keV	45 degree 44keV	Side ^{60}Co	Side 105keV	Side 44keV
Head	.80	.78	.65	.81	.78	.90	.88	1.06	.96
Chest & Abdomen	.77	.99	.71	.68	.64	.55	.58	.50	.30
Arms	.89	.97	.87	.89	.97	.87	.89	.97	.87
							.18	−0	−0
Under arms	.91	1.04	1.00	.91	1.04	1.00	.91	1.04	1.00
							.18	−0	−0
Thighs	.86	.91	.78	.86	.91	.78	.86	.91	.78
							.51	.17	.29
Legs	.86	.95	.79	.86	.95	.79	.86	.95	.79
							.58	.27	.14
Whole body	.82	.97	.78	.77	.78	.70	.60	.54	.41

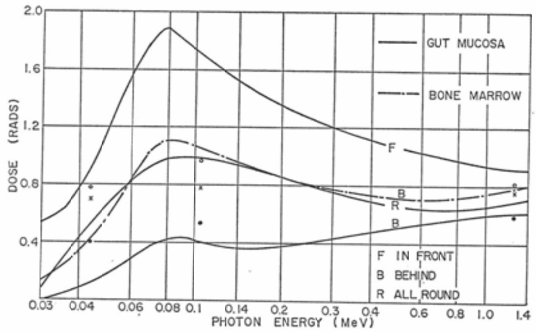
The areas between the equi-exposure lines were measured with a planimeter. The product of the area, the mid-point value of two lines and the roentgen-rad conversion factors divided by the total area gave the absorbed dose in that part. Values for whole body were obtained by weighing by the weight of each part. About the largest exposure regions, as the representative exposure, 0.3 was added to the smaller value of that region. The R-rad conversion factors used were 0.93, 0.95 and 0.95 for 44 keV, 105 keV X-rays and ^{60}Co γ-rays, respectively. Results are shown in Table 2.

Discussion

Present results did not include the consideration of the changes of radiation quality in the phantom.

This gave some errors in the calculation of the absorbed dose through the energy dependence of the chamber and of the R-rad conversion factor. Error of exposure reading in the phantom has been discussed in detail by H.J. Delafield. He estimated that the results were about 5% high at 2 MeV irrespective of depth and that at 1 keV the chamber over-read by about 10% near to the surface and under-read by a few % at 20 cm depth. The R-rad conversion factor changes from 0.92 to 0.96 in the energy range of 30 keV to 1.25 MeV. Moreover, the inhomogeneity of the human body was neglected in the calculation. So, no corrections due to the changes of photon quality have been applied.

Figure 3 shows the comparison of the absorbed dose in the whole body with that in the gut mucosa and bone marrow obtained by A.R. Jones. The results of bone marrow have not differed so much for the frontal, back and rotational irradiation. The points show the present data. Because they were obtained by averaging over the whole body, changes of values with the energy and the direction of beam are rather small. It is possible to say that the absorbed dose in the whole body is close to that in bone marrow.



○ in front; × 45 degrees; ● side

Fig. 3. Comparison of absorbed dose for 1R of free air exposure in whole body and that in critical organs obtained by A.R. Jones (Ref. 3). Points are present data.

The integral dose is affected by the scatter factor and the attenuation of radiation in the human body. The scatter factor is largest around 70 keV and decreases with decreasing field size. If the scatter is neglected, the absorbed dose would be larger when the radiation energy is larger and the path length of radiation is longer (i.e., in case of side incidence). Shielding effects of arms are clearly indicated in Fig.2 and the absorbed dose in the whole body is smallest in the side irradiation. This shows the importance of the field size or the scatter factor.

References

1) ICRP: Publication 9, Pergamon Press, Oxford (1966).
2) Jones, A.R.: Measurement of the dose absorbed in various organs as a function of the external γ-ray exposure. AECL-2240 Chalk River, Ontario (1964).
3) Jones, A.R.: Proposed calibration factors for various dosimeters at different energies, Health Phys. 12 (1966) 663.
4) Piesch, E.: A concept of health physics dosimetry for quantum radiation, Health Phys. 13 (1967) 759.
5) Piesch, E.: The indication of absorbed dose in critical organs by energy independent personnel dosimeters, Health Phys. 15 (1968) 145.
6) Delafield, H.J.: Gamma-ray exposure measurements in a man phantom related to personnel film dosimetry, Phys. Med. Biol. 11 (1966) 63.
7) Langmead W.A. and Hill, S.M.B.: A method of whole body integral dose, 1st Intern. Congr. I.R.P.A., Rome 1966, pp. 479–489.